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Experimental Study of Performance and Emission Characteristics of Honge Oil with Waste Edible Biodiesel Blends

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Abstract

Due to the continuous increase in demand for fossil fuels and emissions of harmful gases, researchers are moving to form biodiesel from biomass with the same thermo-physical properties as pure diesel, lowering combustion exhaust emissions. In the present research work, the transesterification process uses an alkaline catalyst to form second-generation biodiesel from honge seeds and waste edible oil (WEO). The experimental tests are conducted by considering different concentration ratios of honge and Waste edible oil blended biodiesel such as 5H+10W+85D (H stands for 5% honge oil, W stands for 10% WEO oil, and D stands for 85% Diesel), 5H+20W+75D, 10H+5W+85D and 20H+5W+75D, and compared with pure diesel (D100) and bio-oil fuel (H100 & W100). The performance and emissions combustion parameters were measured at five loading conditions: 10%, 30%, 50%, 70%, and 100%. The novelty of the present research is that the blended fuel 5H+10W+85D exhibited a minimum BSFC of 0.23kg/kW-hr with a maximum brake thermal efficiency of 35.99% at a compression ratio of 16.5:1. The CO and HC emissions were also reduced for the biodiesel, but NOx emission is found to be increased.

1. Introduction

Energy is essential to economic expansion, human wellbeing, improving life quality, and societal advancement. The demand for petroleum has increased recently due to a sharp increase in industrialization, improvement, and modernization on a global scale. Diesel is the primary energy source for industry, transportation, and agriculture [1]. Diesel is a widely used energy source because of its versatility, consistency, ease of handling, dependability, and combustion efficiency. Developing nations import oil because they must have it to meet their energy needs. Currently, India imports $7.7 billion (about Rs. 33,000 crore) of oil every month on average; if this trend continues, our annual oil import bill might reach $112 billion (about Rs. 470,000 crore). It is vital to look for an appropriate diesel oil substitute due to the rising cost and demand of fossil fuels, which are linked to greater emissions [2-4].

Fossil fuels are contributing to environmental problems and the rising energy demand that has created an energy crisis [5-7]. Fossil fuel resource depletion and environmental damage are thus the two main problems facing society. The global awareness of the energy crisis and the environmental impact of fossil fuels has prompted investigations into the viability of using alternative energy sources such as biodiesel [8-10]. A clean burning alternative, biodiesel has the advantage of being nontoxic, biodegradable, and free of sulfur and carcinogenic ring components. It is made up of methyl and methyl esters (medium length C16–C18), which are alkyl esters of fatty acids [11–14]. Many studies have examined different biodiesels and their blends; among the resources that have been thoroughly investigated and from which biodiesel can be produced are Calophyllum inophyllum (CI) or Polanga, waste cooking oil (WCO), and Pongamia pinnate (PP); the transesterification process for biodiesel production, in particular, uses monohydric alcohols like ethanol and methanol with NaOH catalyst [7]. Depending on the free fatty acid content, different transesterification phases are used to produce biodiesel [15, 16]. Various techniques were used to produce different biofuels from the agro-industrial wastes, including biogas, biohydrogen, bioethanol, and biodiesel [17,18].

Atgur et al. [19] use thermogravitometry and differential scanning calorimetry (TG-DSC) curves for the particular 10 °C/min heating rate in atmospheric air to investigate the thermal properties of jatropha (Jatropha curcas), honge (Pongamia pinnata), and their equal mix. Blended biodiesel promises improved combustion properties by lowering the intensity of combustion (Hf). Therefore, mixed biodiesel demonstrates the possibility of an effective substitute energy source. Banapurmath et al. [2] investigated the viability of common alternative energy sources such as Honge, Rice Bran, and Neem oils as vegetable oils, and combinations of these oils were produced in dual fuel mode. Experiments were conducted to optimize each chosen fuel combination's injection pressure and timings. When using producer gas in dual fuel mode, the engine's braking thermal efficiency is determined to be 24, 20, 19, and 17% for all injected fuels, including diesel, Honge, Rice Barn, and Neem oils. The study conducted by Channappagoudra et al. [20] aimed to understand how injection timing affected the modified dual fuel (B20áBio-CNG) engine. The engine's variables (injector opening pressure (IOP), injection timing (IT), compression ratio (CR), nozzle hole (NH), and piston cup geometry were optimized. The results show in terms of single fuel operation, the modified engine performed better than the standard engine. The modified engine with advanced injection timing of 29° before top dead centre has demonstrated superior performance, combustion, and emission characteristics when compared to the other injection timings, according to the dual fuel (B20+Bio-CNG) experimental investigation. Riyadi et al. [21] reviewed the impact of biodiesel fuel on HCCI engines. Biodiesel fuel has the potential to reduce smoke emissions, toxic pollutants, including CO and HC from engines, and improve combustion characteristics and engine performance. Nayak et al. [22] briefly describe the combustion performance and emission characteristics of different blended biodiesel (PMBD10, PMBD20, WBD10, WBD20, FBD10, FBD20, WBD100, and FBD100) in a direct-injected single-cylinder four-stroke diesel engine. The findings showed that PMBD20 exhibited a strong similarity to diesel fuel. Elkelawy et al. [23] examined the significance of the response surface approach in forecasting the best operating parameters and emissions for diesel engines running on mixtures of diesel, alternative fuels, and nanoparticle additives. The utilization of biofuel blends with alternative fuels, and amounts of nanoparticle additives in diesel engine combustion, a response surface approach can provide precise results while saving costs and time. Li et al. [24] examined how castor seed oil affected a diesel engine's emissions and performance. The results showed decreased CO and HC but increased NOx for 10.2%, 10.9%, and 13.3%, respectively. Panwar et al. [25] conducted experiments on a single-cylinder diesel engine utilizing castor biodiesel at B0, B5, B10, and B20 volume proportions. Compared to B0, B5, and B20, the results showed a higher BP of 1.87% and a reduced SFC of 5.5% at maximum load. It was observed that NOx was higher than expected when considering the emission standards, even under part-load and full-load conditions. Nayak et al. [26] examined the use of Jatropha biodiesel on diesel engines operating in naturally aspirated mode as a substitute fuel. The results show a 7.9% increase in BTE, a 9% increase in BSFC, and a maximum loading condition. Recently Kaya and Kökkülünk [27] used 20% (B20), 50% (B50), and 100% (B100) of waste frying oil biodiesel (WFOB)–diesel blends investigated theoretically and experimentally. They found that using biodiesel reduces the exergy destruction rate by up to 7.03% and increases exergetic efficiency by up to 5.86% compared to diesel for engine speed between 2700 and 3000 rpm. Arunkumar et al. [28] investigated the usability of castor biodiesel, which reduced carbon monoxide up to 9% and HC reduced by 8.8% compared to diesel and also had a considerable reduction in oxides of nitrogen. Shrivastava et al. [29] produced biodiesel LA20 (20% Roselle + 80% diesel) and KB20 (20% Karanja + 80%) diesel from Roselle and Karanja oil by using the transesterification process and experimentally examined at different engine loads with constant engine speed. The results demonstrated improvements in brake-specific fuel consumption of 6.84% and carbon dioxide emissions of 3.73% with a reduction in NOx and smoke emissions by 6.01% and 12.59%, respectively, for LA20. Whereas, KB20 demonstrated a rise in brake specific fuel consumption of up to 8.5%, but a decrease in brake thermal efficiency, exhaust temperature, NOx, and smoke emissions by 1.82, 1.64, 3.83, and 13.63%, respectively. Rajak and Verma [30] involve the numerical simulation of the diesel engine using Diesel-RK, a tool for determining engine characteristics for diesel, vegetable oil, animal fats, waste oils, and alcohols, respectively. The study shows that maximum power and cylinder peak pressure were obtained at 17.65% for coconut oil and 1.5%, 0.77%, 2.3%, and 17.8% for rapeseed oil, fish oil, veal oil, waste frying oil, and propanol biodiesel, respectively. Sonachalam et al. [31, 32] used blends of 5 % and 10 % ethanol with waste cooking oil biodiesel and mixed nano-additives, multi-walled carbon nanotubes (MWCNT) at a concentration of 30 ppm. The results show that the 30 ppm MWCNT in B20+E10 blends is most effective for improving engine performance and emissions. Further, they examined engine parameters for a dual fuel engine that runs on biodiesel blends made from 20 % methyl ester of chlorella protothecoides micro algae (B20MEOA) and acetylene gas under variable fuel injection pressure (FIP) ranging from 200 bar to 240 bar with 10-bar steps. All tested emissions except NO_x are reduced in dual fuel combustion when the B20MEOA is injected at 240 bar.

The above literature review shows that the performance and exhaust emissions can be analyzed using different biodiesel blends with various concentration ratios. In this research work, biodiesel is formed from honge seeds and waste edible oil (WEO) by the transesterification process using an alkaline catalyst. The experimental tests are conducted by considering different concentration ratios of honge and Waste edible oil blended biodiesel, such as D100, H100, W100, 5H+10W+85D, 5H+20W+75D, 10H+5W+85D, and 20H+5W+75D, and compared with pure diesel and bio-oil fuel. The blend 5H+5W+90D (H stands for honge biodiesel, W stands for WEO biodiesel, and D stands for Diesel, i.e., 5% H, 5% WEO Biodiesel, and 90% D) is mixed to form the blended biodiesel. The performance parameters, such as brake thermal efficiency, brake specific fuel consumption, brake power, and exhaust emissions, are measured at five loading conditions of 10%, 30%, 50%, 70%, and 100%.

2. Materials and Production Process

2.1 Production of Honge Biodiesel

A one-stage (Alkaline Catalyzed Transesterification) procedure was employed since the free fatty acid (FFA) Value of honge oil was recorded at 2.41%. One liter of honge oil is put into a flask with three necks. This three-neck flask is set over a magnetic stirrer that contains a magnetic pellet. The Reflex Condenser is now fastened to the 3-Neck flask's central neck. The water pipeline is attached to the condenser and tested to ensure water flows from the tap to the output and the condenser. In order to achieve a uniform heating of the oil, the magnetic stirrer is then turned on, the heating control is set to 60 °C, and the speed is regulated between 600 and 800 rpm. Now fill the thermowell with oil and place it inside the 3-Neck flask's side neck. A temperature reading can be taken by inserting the thermometer into the thermowell. Now fill a 500 ml beaker with 300 ml of methanol for every liter of oil. Weigh the six grams of NaOH (using the FFA% of the raw oil that was previously measured) and mix it with the methanol. This mixture is known as the "methoxide" mixture; stir thoroughly. The methoxide mixture is gradually added to the hot oil inside the 3-Neck flask through the loading opening neck when the temperature reaches 63 °C while maintaining a speed of 600 rpm. A stopper is now used to seal the opening neck. A condenser keeps the temperature between 60 - 63 °C while the process runs for two hours. The mixture's color changes to a transparent, cold crimson. Turn off the electricity and take off the reflux condenser. After transferring the mixture into a separating funnel, give it two hours to settle. After two hours, the top layer of biodiesel separates, and the glycerine settles to the bottom. Carefully empty the separating funnel's bottom of glycerine before storing it.

2.2 Production of WEO Biodiesel

Since the FFA Value of WEO was found to be 5.69% a two-stage (acid-catalyzed transesterification) process was used. One liter of WEO is taken in a 3-Neck flask with a magnetic pellet. Stirrer speed is maintained at 600-800 rpm. The reflux condenser is fixed and checked for water circulation, which is used to maintain a uniform temperature of 60 °C. After that, 150 ml of methanol is taken in a 500 ml capacity beaker, and 1.50 ml of concentrated sulphuric acid (based on FFA% % determined earlier) is added to the methanol. This mixture is added to the oil very slowly and carefully through the loading neck of the 3-Neck flask. It is then agitated in the 3-Neck flask at 60 °C for 1-1.5 hours as shown in Fig. 1. A dark layer is observed at the top layer of the oil. The mixture is transferred to the separating funnel and allowed to settle for 2 hours. The acid layer will rise to the top as a black layer, as shown in Fig. 2. The bottom layer is drained to the 3-Neck flask. The top layer is drained and stored separately. The sample of the bottom layer from the 3-Neck flask is taken, and the new FFA is measured and found to be 4.51%. Since the new FFA is more than 2 %, the above procedure is again repeated, taking 1.25 ml of concentrated sulphuric acid (based on FFA% determined). The new FFA is now measured and found to be 0.33 %.

Now, 150 ml of methanol per liter of oil is taken, and the calculated quantity of NaOH (as per the new FFA) is added and mixed in a beaker (Methoxide mixture). It is then added to the 3-Neck flask slowly. After adding “methoxide mixture” into the 3-Neck flask, the mixture is agitated at a suitable RPM and the temperature is maintained at 63 °C for 1 to 1.5 hours. It is noted that the mixture's color changes to a clear, cold red. Turn off the electricity and take off the reflux condenser. As illustrated in Fig. 3, transfer the mixture into a separating funnel and let it settle for two hours. After 2 hours, the glycerine settles down at the bottom, and the Biodiesel separates as the top layer. Glycerine is drained from the bottom of the separating funnel carefully and stored. After that, biodiesel washed in another funnel as shown in Fig. 4.

Fig. 1 *Heating of WEO*

Fig. 2 *Formation of the Acid layer at the top*

Fig. 3 *Separation of biodiesel & glycerine*

Fig. 4 *Biodiesel washing*

2.3 Preparation of Blends

Based on the required quantity of blended biodiesel, both biodiesel (honge & WEO) and diesel are calculated and mixed together to form the blend. For example, the blend 5H+10W+85D (here H stands for honge biodiesel, W stands for WEO biodiesel, and D stands for Diesel) means 5% of honge biodiesel, 10% of WEO Biodiesel, and 85% of diesel is mixed to form the blend. Similarly, other blends are named based on the percentage of biodiesel and diesel shown in Table 1. The thermophysical properties of all pure diesel, honge, WEO, and their blends are shown in Table 2. Blends of 5H+10W+85D, 5H+20W+75D, 10H+5W+85D, and 20H+5W+75D are preferred over higher blends like B50 because they strike a balance between engine performance, pollution control, and fuel cost. Higher blends can cause engine wear, cold flow problems, and increased NO_x emissions, but selected blends are compatible with existing engines and infrastructure. Furthermore, economic issues such as feedstock availability and fuel regulations make selected blends more suitable for broad use.

Table 1 Composition of Honge & WEO blends

Sl. No.	Blends	Composition, %		
		Honge Biodiesel (H100)	Waste Edible oil Biodiesel (W100)	Diesel (D100)
1	5H+10W+85D	5%	10%	85%
2	5H+20W+75D	5%	20%	75%
3	10H+5W+85D	10%	5%	85%
4	20H+5W+75D	20%	5%	75%

Table 2 *Properties of selected fuels*

SI.NO	Diesel (%)	Biodiesel (%)		Density (kg/m³)	Kinematic viscosity (cst @ 40 °C)	Specific gravity	Calorific Value (kJ/kg)	Flash Point (°C)
		Honge	WEO					
1.	100	-	-	823	2.38	0.823	43033	38
2.	-	100	-	834	5.50	0.834	34902	206
3.	-	-	100	833	4.89	0.833	35457	218
4.	85	5	10	766	2.92	0.766	41869	50
5.	75	5	20	764	3.17	0.764	41111	48
6.	85	10	5	798	3.67	0.798	41841	48
7.	75	20	5	794	3.09	0.794	41028	48

3. Experimental Setup

A computerized single-cylinder, four-stroke, water-cooled CI engine test rig was used for the experiments. Figure 5 shows the experimental setup of a four-stroke diesel engine for determining the effects on the performance and emission characteristics of a compression ignition (CI) engine by using a combination of pure diesel, honge, and waste edible oil and its blended biodiesel fuel. The temperature sensors are required to measure the temperature of jacket water and the exhaust gas inlet and outlet. Pressure sensors are also included to measure fuel injection and combustion gas pressure. The CI engine is directly linked to an eddy current dynamometer, which allows the engine to run at full or under load. The software supplied the density and calorific value of the specific fuel to calculate the aforementioned performance metric for various mixed biodiesel blends. The control panel is linked to a computer for recording test parameters like fuel flow rate, temperature, air flow rate, load, etc., and computing engine performance characteristics like BP, BSFC, and BTE. In parallel, the exhaust gas analyzer evaluates NOx, CO, and HC emission parameters.

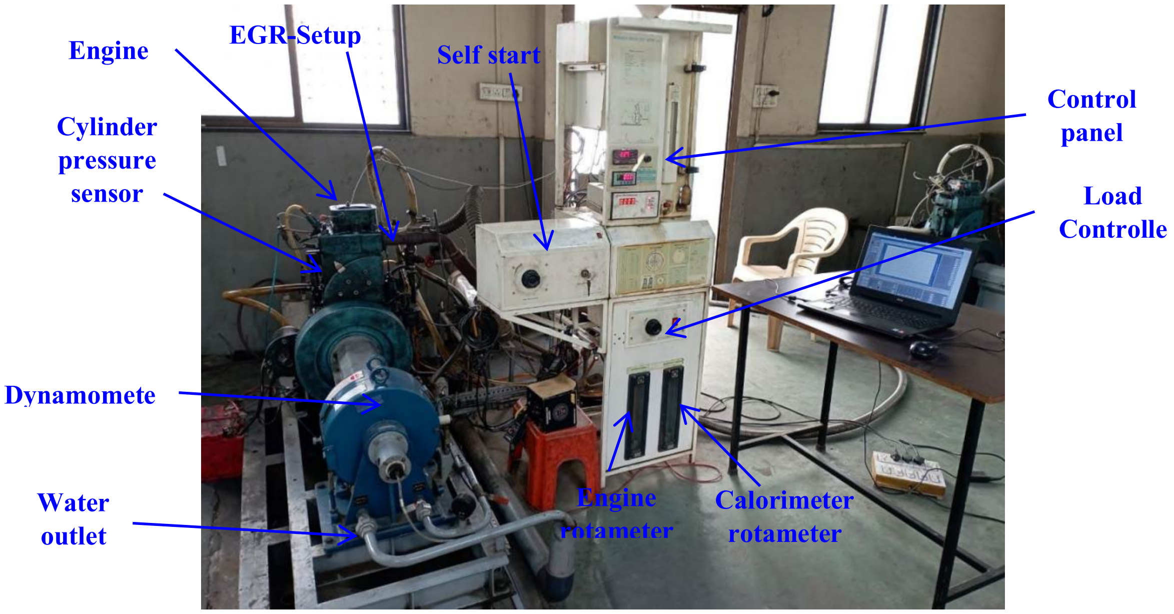

Fig. 5 *Experimental setup of the four-stroke diesel engine*

4. Results and Discussions

4.1 Brake Power (BP)

The brake power of Honge and WEO, and their blends, are represented at various engine load conditions. The brake power developed by the engine increases with an increase in load on the engine for all blended fuels as well as pure diesel, as shown in Fig. 6. The viscosity of Honge and WEO blended biodiesel is higher, which results in a lower cetane number, which helps in mixing and becomes a fine air-fuel mixture inside the cylinder. Due to proper mixing and shorter ignition time, the brake power. At full load conditions, the brake power of diesel, honge, and Waste edible oil blended biodiesel such as D100, H100, W100, 5H+10W+85D, 5H+20W+75D, 10H+5W+85D, and 20H+5W+75D are produced 3.66 kW, 3.61 kW, 3.59 kW, 3.63 kW, 3.63 kW, 3.64 kW, and 3.63 kW, respectively. The results show that all blended biodiesel has approximately similar BP to pure diesel. However, pure honge and Waste edible oil have comparatively low BP

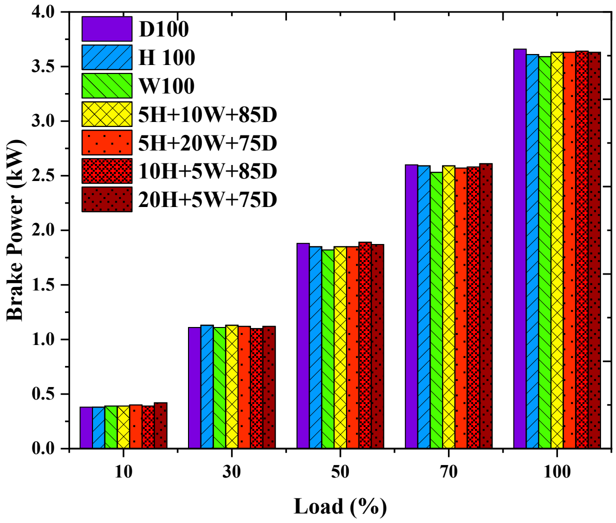

Fig. 6 *Comparative analysis of the brake power for different blended biodiesels*

4.2 Brake Specific Fuel Consumption (BSFC)

The brake specific fuel consumption (BSFC) of pure and blended biodiesel fuels is illustrated at different engine loads as shown in Fig. 7. As the load increases, the brake specific fuel consumption for all neat biodiesel and blends decreases. The BSFC decreases significantly with load for all the fuels as the power output per unit fuel consumption increases at higher loads. It was found that the BSFC of H100 & W100 is always higher due to the esters of vegetable oils having lower heating values as compared to diesel. At full load condition, blend 5H+10W+85D shows a minimum brake specific fuel consumption of 0.23 kg/kWh compared to other pure and blended biofuels. Because of partial fuel combustion, fuel consumption is higher at lower compression ratios. As a result, the reduction in BSFC can be attributed to more efficient fuel utilization at higher compression ratios, where increased cylinder temperature and pressure from charge dilution improve combustion. In biodiesel tests, typical compression ratios for diesel engines ranged from 16:1 to 18:1. As mentioned earlier in this research, a compression ratio of 16.5:1 is selected. Changing this compression ratio influences its efficiency, power output, and emissions. If the compression ratio increases, it improves thermal efficiency, resulting in increased fuel economy and power. However, a high ratio might result in knocking and increased NOx emissions. Selected compression ratios mitigate these concerns but may reduce efficiency and output.

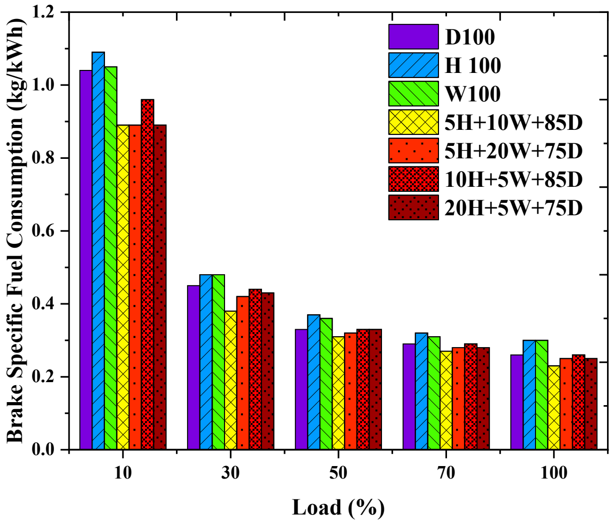

Fig. 7 *Comparative analysis of the brake specific fuel consumption for different blended biodiesels*

4.3 Brake Thermal Efficiency (BTE)

Fig. 8 shows the brake thermal efficiency (BTE) variation for different biodiesel blends at different loads. As the load increases, brake power also increases; hence, brake thermal efficiency increases because brake power is directly proportional to brake torque. From Fig. 8, it can be observed that D100 has lower brake thermal efficiency compared to other pure and blended biofuels at each loading condition. However, the BTE of H100 and W100 has comparatively more BTE at 50% and 70% loading conditions. At full load condition, the BTE of diesel, honge, and Waste edible oil blended biodiesel such as D100, H100, W100, 5H+10W+85D, 5H+20W+75D, 10H+5W+85D, and 20H+5W+75D are produced at 32.27%, 35.68%, 36.49%, 36.99%, 34.32%, 34.06%, and 34.79% respectively. Hence, the blend 5H+10W+85D shows a maximum BTE of 36.99% at full load condition. Because biodiesel burns more efficiently and the fuel mixes more thoroughly, it has better lubrication, which improves brake thermal efficiency.

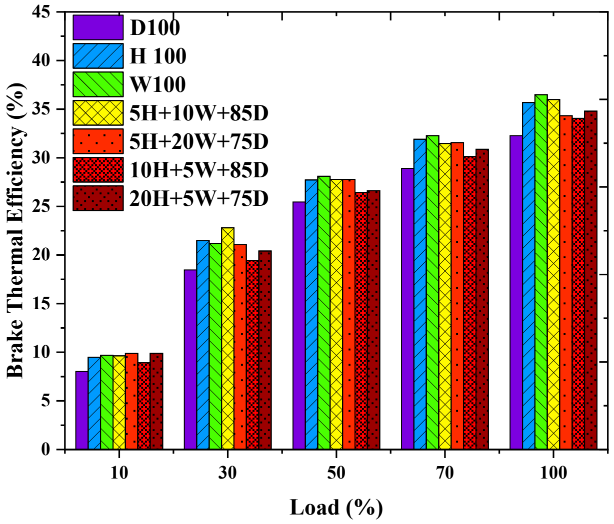

Fig. 8 *Comparative analysis of the brake thermal efficiency for different blended biodiesels*

4.4 Carbon Monoxide (CO)

The variation of carbon monoxide (CO) for different biodiesel blends at different loads is shown in Fig. 9. It can be observed that the CO emission for diesel is high compared to other biofuels. The incomplete combustion caused the formation of CO emissions because the oxidation process did not have enough time to complete combustion. The CO formation also depends upon mixture strength, i.e., oxygen quantity and fuel viscosity, which, in turn, depends on atomization. Since the fuel consumption of blended biofuels increases and the A/F is high, it leads to complete combustion. The CO emission increases as the load increases. Thus, the fact that biodiesel emits less CO than diesel is probably because it contains some oxygen by nature, which aids in the fuel's more thorough oxidation. CO emission for H100 and W100 is low compared to other blended biodiesels. At all loading conditions, diesel has high CO emissions as compared to other biodiesels. At full load condition, the CO emission of diesel, honge and Waste edible oil blended biodiesel such as D100, H100, W100, 5H+10W+85D, 5H+20W+75D, 10H+5W+85D, and 20H+5W+75D are produced 0.067% of Vol., 0.033% of Vol., 0.028% of Vol., 0.046% of Vol., 0.058% of Vol., 0.062% of Vol., and 0.058% of Vol., respectively.

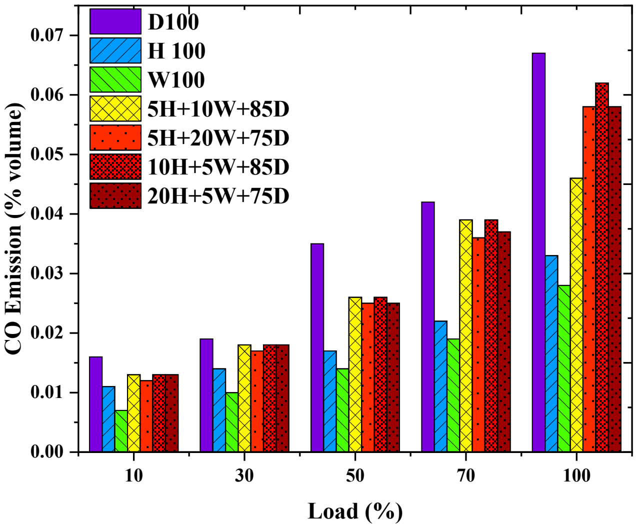

Fig. 9 *Comparative analysis of the CO emission for different blended biodiesels*

4.5 Unburned Hydrocarbons (HC)

The formation of unburnt hydrocarbon emission from diesel, honge, and Waste edible oil blended biodiesel (D100, H100, W100, 5H+10W+85D, 5H+20W+75D, 10H+5W+85D, and 20H+5W+75D) for various loads is shown in Fig. 10. It is observed that the HC emission fluctuated at a higher compression ratio for all the loads. It was observed that pure and blended biodiesel show lower HC emissions at each loading condition. This is because, with higher compression ratios, the combustion chamber's burned gases burn at a higher temperature, which prevents the condensation of more hydrocarbons and reduces the amount of unburned hydrocarbons. However, the heavier hydrocarbon particles that are present in diesel fuel increase HC emissions in diesel. The built-in oxygen in biodiesel may also be responsible for this reduction in unburnt HC. At full load, HC emissions increase due to relatively less oxygen available for the reaction.

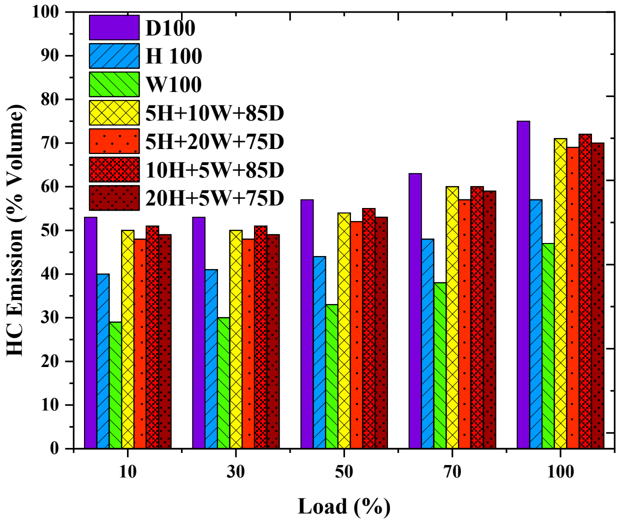

Fig. 10 *Comparative analysis of the HC emission for different blended biodiesels*

4.6 Oxides of Nitrogen (NO_x)

The formation of NO_x is highly dependent on cylinder temperature, oxygen concentration, and residence time for the reaction to take place. NO_x emission is one of the most critical emissions from the CI engines. The NOx emission for different blended biodiesels at various loads is shown in Fig. 11. It is observed that the NOx emission increased with increasing load for all biodiesels. Because biodiesel contains oxygen and burns at a higher temperature, there is an increase in NO_x emissions. Results show that biodiesel H100 and W100 have comparatively higher NO_x emissions than that of diesel. The NO_x emission of other blended biodiesel is very close to that of diesel at each loading condition.

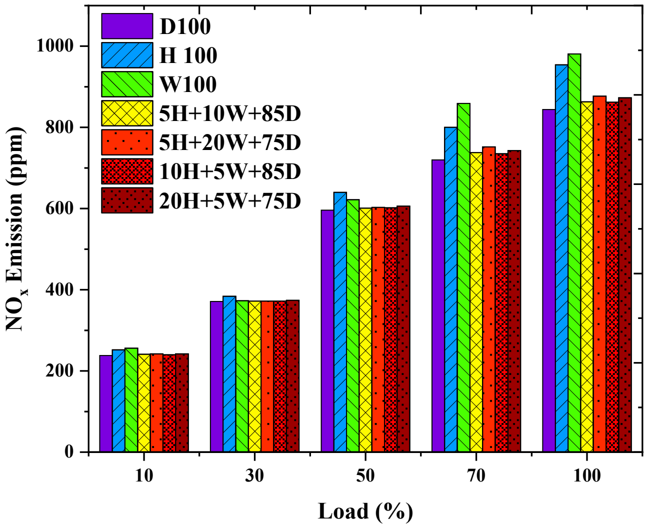

Fig. 11 *Comparative analysis of the* NO_x *emission for different blended biodiesels*

5. Conclusions

In the present study, initial biodiesel fuels are formed by the transesterification process of raw material, which has physical properties closer to those of diesel fuel. The performance characteristics, such as fuel consumption, brake thermal efficiency, and emissions of CO, HC, and NOx of a compression ignition (CI) diesel engine, have been investigated at a compression ratio of 16.5. The following conclusions are drawn:

- As the load increased, the engine's brake power also increased. The blend 5W+10H+85D shows a maximum brake power of 3.67 kW at a compression ratio of 16.5:1.
- Biofuel blends have a higher BSFC than diesel when operating at low load or startup conditions. The blended fuel 5H+10W+85D exhibited a minimum basic 0.23kg/kW-hr at a compression ratio of 16.5:1.
- Brake thermal efficiency was found to increase with load. The blended fuel 5H+10W+85D showed a maximum brake thermal efficiency of 35.99% at a compression ratio of 16.5:1. However, other blends have brake thermal efficiency close to that of diesel.
- CO and HC emissions were also reduced for biodiesel and even diesel at a compression ratio of 16.5:1. However, NOx emissions were similar to diesel.

This article's use of selected blends demonstrates the benefits of efficiency and emissions. However, these findings have drawbacks, including a lack of real-world testing across multiple engines, long-term performance data, and changeable environmental conditions. These characteristics can substantially impact the findings' applicability and scalability.

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Conflict of Interest

The authors declare no conflict of interest regarding the paper's publication.

Author Contribution

The authors confirm contribution to the paper as follows: ***study conception and design:*** *C S Srinivasa and B H Maruthi Prashanth;* ***data collection:*** *C S Srinivasa and B H Maruthi Prashanth;* ***analysis and interpretation of results:*** *C S Srinivasa, B H Maruthi Prashanth, Noor Alam and S Ramesh;* ***draft manuscript preparation:*** *Mahammadsalman Warimani and Noor Alam. All authors reviewed the results and approved the final version of the manuscript.*

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